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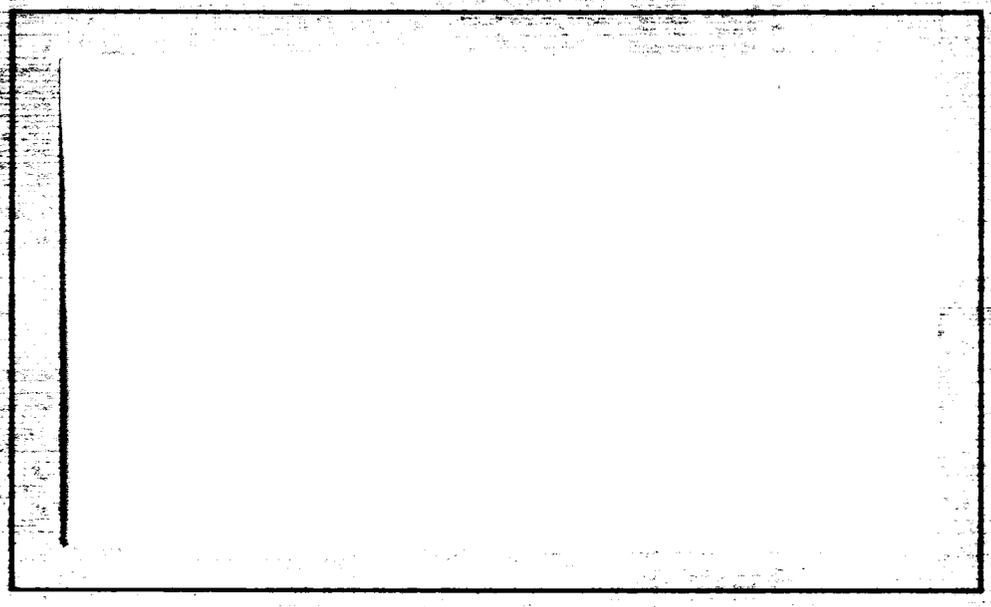

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REPORT NO. 7129-933002

SECOND QUARTERLY PROGRESS REPORT

ON

RESEARCH ON ZERO-GRAVITY EXPULSION TECHNIQUES

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FOREWORD

This quarterly report was prepared by the Bell Aerosystems Company under NASA Ccntract No. NASr-44. Mr. Alexander Krivetsky acted as Technical Director on the project.

The work is being monitored by Mr. Henry Burlage of the NASA Washington Office, who is the Project Manager on this expulsion techniques contract. Mr. Burlage is Assistant Chief, Liquid Rockets for Advanced Technology for the NASA. Mr. Richard Porter of the Jet Propulsion Laboratory, Californis Institute of Technology, is the Technical Monitor on this program.

The following technical personnel of the Bell Aerosystems Company were associated with the project during this period:

Durwood Anderson
William Bauer
William Buckley
Joseph Padlog
Edward Phillips
John V. Robinson
Clayton Williams

INTRODUCTION

This is the Second Quarterly Progress Report for Contract NASr-44, "Research on Zero-Gravity Expulsion Techniques" and covers the period from August 1, 1961 to November 1, 1961.

As mentioned in the First Quarterly Report, the basic objective of the program is the consideration of techniques for positive expulsion systems operating in space environments and under environments induced by gusts, accelerations, etc. The actual choice of a positive expulsion device or system is dependent upon the mission and space vehicle requirements which gives the criteria leading to the selection of a certain expulsion device.

It was originally intended that this goal would be achieved by describing various expulsion system concepts and their characteristics; by establishing suitable design methods; by considering the peculiarities of materials in the design; and finally by actual construction and testing of the most promising configuration concept. Following discussions with the NASA Program Manager, this latter step of construction and testing has been de-emphasized.

Work during this quarter was directed toward screening the most promising devices from the morphological study. Approximately twelve of these concepts were then subjected to a mission analysis with the object being the selection of the most practical

device(s). Two devices were selected for a detailed design and test program. These were the double convoluted spherical and longitudinal diaphragms.

A detailed test program for demonstrating the feasibility of these concepts was outlined, consistent with the time remaining in the program. Bell Aerosystems Company and NASA personnel reviewed the status of the program at this time. Following this review, the system test program was de-emphasized and work is to continue on additional concepts of expulsion. More detailed results of the review are presented in the section "Future Work".

WORK ACCOMPLISHED

Literature Survey Review

The literature search on positive expulsion devices is being continued. By and large the major effort here was completed during the first quarter of the program. Most of the literature uncovered since then did not disclose much information on the subject. Many references dealt mainly with weightlessness, the associated life support system, and its effect on man and animals.

In a few instances, references were made to positive expulsion devices but these were based on flexible plastic bladder configurations for propellant expulsion. Squeeze-type tubes as food containers for feeding of astronauts were mentioned in some cases as another type of positive expulsion device.

Design Criteria

Requirements and criteria have been established to provide a basis for design and test of positive expulsion devices. Expulsion devices were classified in terms of: (a) time of exposure to propellants and/or space radiation, (b) required life or cycles of propellant expulsion, and (c) size or volume of propellants to be expelled.

The representative design criteria is based on a survey of several sattelite and space probe missions and simplifications in the requirements have been introduced where possible because of the general nature of the present study as compared to the specific applications associated with the survey specifications.

Positive Expulsion Techniques

The investigation of the various types of expulsion techniques disclosed that the operating principles, geometry and control of the devices could be classified into certain categories, groups and subgroups.

Actually, two major force concepts (forces that move the fluid) are involved in positive expulsion systems. These two forces are:

I - "Contact-Force" Movement

II - "Distant-Acting-Field-Force" Movement

"Contact-force" movement is attributed to a mechanical displacement device wherein contact with the fluid is provided to

insure movement. This concept includes the following categories of devices:

a. Diaphragm-type Configurations

b. Bladder-type Configurations

c. Mechanical Systems

d. Propellant Orientation Systems

e. Surface Forces

f. Chemical Systems

g. Hybrid or Combination of Systems

In the "distant-acting-field-force" movement concept, a force field is involved that may not have any mutual mechanical contact with the fluid. Gravity is an example of a "distant-acting-field-force". The term zero-gravity is actually a misnomer since the effect is caused by the vehicle and its contents both experiencing the same gravitational force which varies with the locale or position, but which is never zero. It is the acceleration of the contained matter relative to the vehicle which is zero. The principal effect of zero gravity is the absence of body forces. Every body retains its mass but does not exert any weight forces on its environment.

A magnetic field is another concept of a "distant-acting-field-force".

The numerous methods of positive expulsion devices that have been screened on the subject program study to date are indicated on the chart on the following page.

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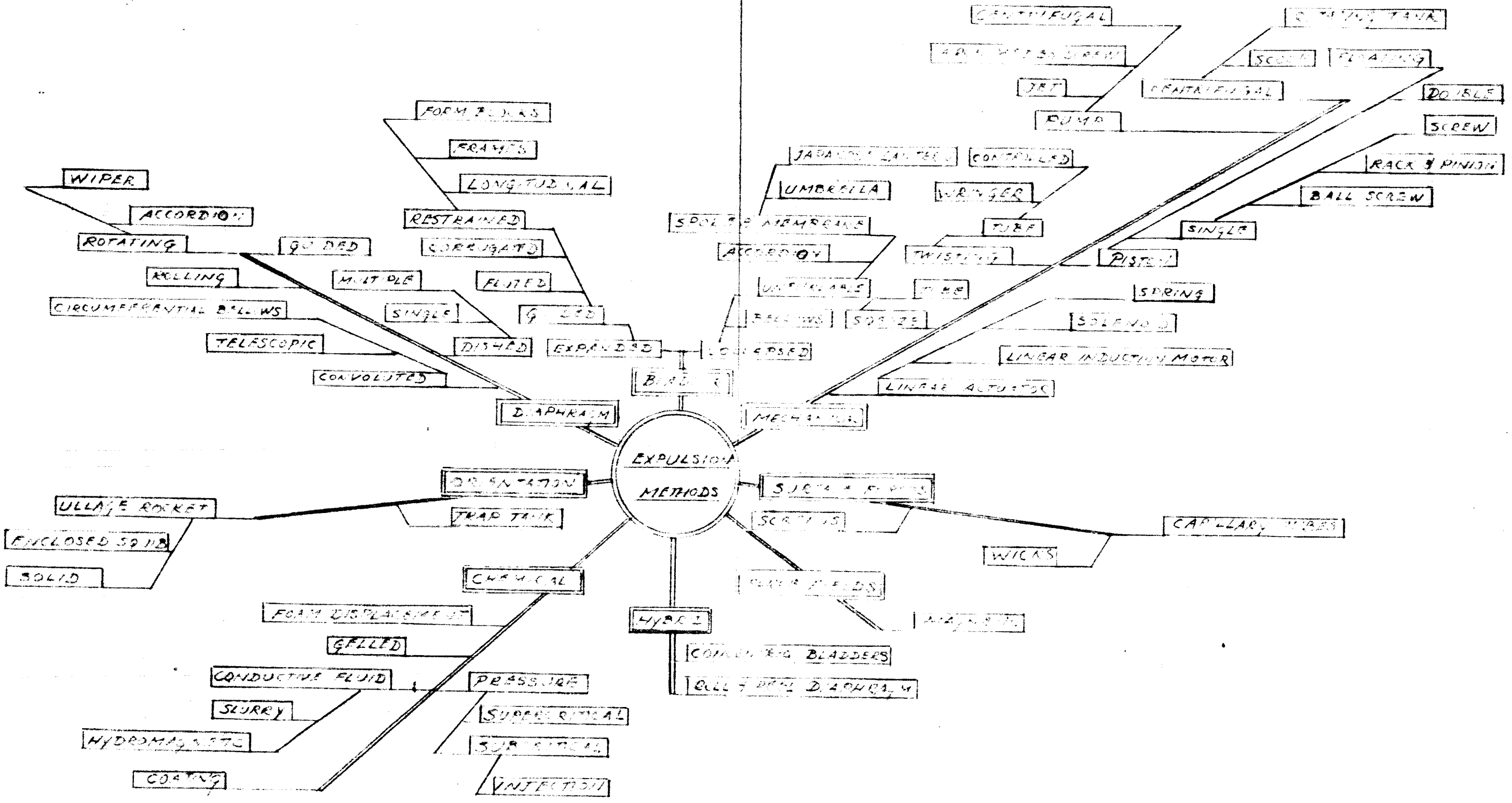

POSITIVE EXPULSION METHODS

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Selection of Promising Techniques

A preliminary qualitative rating scheme was mentioned in the First Quarterly Progress Report. In the present quarter, the scheme was extended by weighing the various characteristics of the numerous devices. An arbitrary rating scheme was devised to evaluate and screen each device from a standpoint of desirable, undesirable and inherent characteristics. The method consists of summing up the total number of desirable and undesirable characteristics and then computing the percentage of desirable ones from the total. The following is a list of the positive expulsion device that has been selected by the above-mentioned method in their relative order of merit.

1. Ullage Rocket
2. Trap Tank
3. Convoluted Metal Diaphragm
4. Plastic Expanding Bladder
5. Fluted Plastic Expanding Bladder
6. Collapsing Metal Cells
7. Framed Plastic Bladder
8. Plastic Diaphragm
9. Metal Diaphragm
10. Plastic Collapsing Bladder
11. Metal Bellows
12. Pressure Piston

Examination of the above listing of devices indicates a need for some specific design data information for further

investigation. Material selection must not only meet the mission environment but the propellant compatibility requirements as well as the desirable properties of stiffness and elongation. The section under "Detail Design Data" presents some of the design information generated during the past quarter period that is necessary for further investigation of these expulsion devices.

The design of an expulsion bladder or diaphragm does not present an opportunity for a detail stress analysis and the associated material selection. The primary requisite for the material is a capability to withstand folding, buckling, and wrinkling without tearing or rupturing. The elongation is a most important characteristic, leaving very little basis for the selection of a gage on the basis of structural requirements.

Selection of Test Device

In the selection of a configuration for fabrication and test during the current program, some additional considerations were taken into account to narrow the choice. The fabrication and demonstration of the feasibility of the device had to be consistent with the time remaining in the program. Because of the program costs, additional concepts under consideration had to be dismissed. Plastic or non-metallic material configurations were disregarded because of the work being performed by other organizations and material manufacturers.

This procedure of selection indicated that the double convoluted metal diaphragm merits further investigation and test.

The Convoluted Diaphragm

Since the double convoluted metal diaphragm indicated many desirable features, it deserved further study and development. Metals were considered to be the primary material choice for bladders and diaphragms because of their capability to withstand the required environment and criterial. In this case, the 1100-0 aluminum alloy indicated the desirable properties from the standpoint of mechanical, physical, and fabrication viewpoints.

From theoretical stress free considerations, the studies have shown that an ideal configuration for the convoluted diaphragm would be a folded membrane approaching zero thickness. Such a membrane would be stress free during deformation from its initial configuration to the final expanded shape if all the fibers do not grow or contract during deformation. This ideal shape is approached if the diaphragm consists of closely packed folds or corrugations with amplitudes (height of fold) which vary nonlinearly from the center of the diaphragm to the edge. These closely spaced folds must be such that its developed area equals half the area of the enclosing body or tank.

Variations from the ideal diaphragm shape as dictated by fabrication methods and metal flexibility has led to a somewhat expanded variable pitch corrugation. During deformation to the expanded shape of the inside contour of the tank, these metal diaphragms experience both bending and membrane stresses as well as plastic strains. As a consequence of the expanded

corrugation pitch, compressive stresses are introduced in alternating legs of the folds of the corrugations during the large deformation process. As a result of compressive stresses, unavoidable buckling at certain stages during deformation will occur. To avoid undesirable diamond-shaped buckling patterns that are a characteristic of conical and cylindrical shells in compression, the lengths of the portions of the corrugation segments were restricted to give a more tenable buckling form characteristic of short, wide plates. A sample sketch of such a corrugation is shown on page 10. A sketch of the double convoluted diaphragm for a spherical and longitudinal tank is also shown on the same page. Some of the advantages and disadvantages of such a system configuration are indicated below.

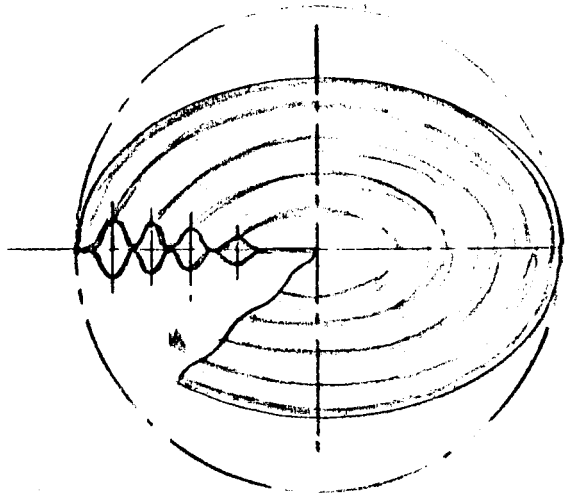
1. Advantages

a. The circumferential corrugations or convolutes can be designed so that the developed length fits the inside contour of the outer shell. Stretching or elongation of the diaphragm is thus minimized. Spherical and longitudinal tanks can employ these diaphragms.

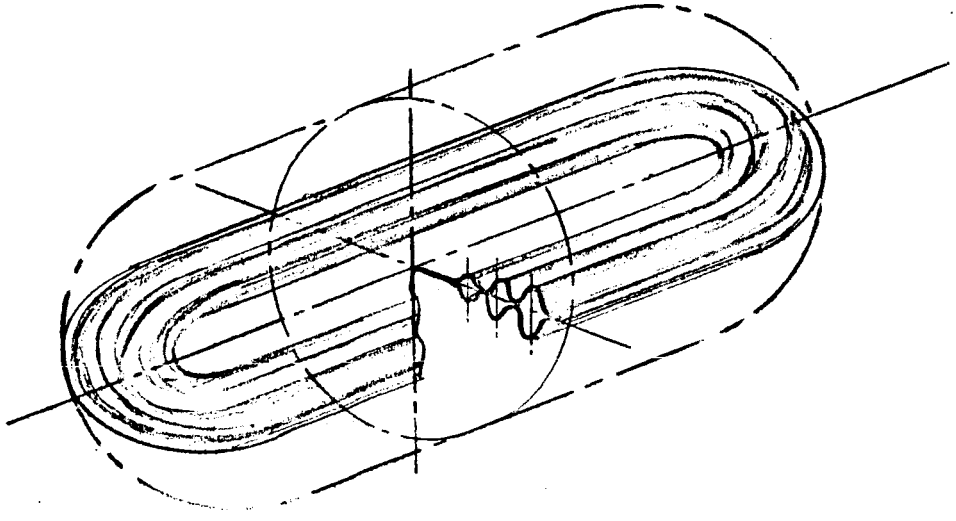
b. The diaphragm is merely an orthotropic plate that is relatively easy to make and handle.

c. Pressurizing gas is introduced between the two diaphragms and the resulting plate deflection does not induce any creases, folds or buckling of the surfaces.

d. The two halves of the convoluted diaphragm can be welded and assembled as a unit which constitutes a pre-formed and pre-folded bladder in the flat.



SPHERICAL TANK



LONGITUDINAL TANK

DOUBLE CONVOLUTED DIAPHRAGMS

e. Partial expulsion cycle testing is possible with this configuration.

f. Each of the two volumes produced by the double convoluted diaphragm can be used for a bi-propellant system within a single tank configuration.

2. Disadvantages

a. Installation of a double convoluted diaphragm requires a circumferential and/or longitudinal bolt-type flange about the tank centerline. This induces a weight penalty.

b. The double diaphragm produces two tank volumes that must be interconnected by a collector tube to insure filling and expulsion from both halves of the tank, if only one propellant is employed.

Detail Design Data

In the study and selection of promising expulsion techniques, certain design requirements became apparent. In order to insure the availability of the necessary information for design and analysis purposes, data was obtained on candidate materials and on structural analysis methods.

Numerous material property considerations must be taken into account in the design of a tank expulsion device to meet the operational and environmental criteria. The operational environment must take into account compatibility and permeability of the materials and the induced and space environment must consider the effects of vacuum and radiation. Both metals and

non-metals can be employed in tanks and expulsion devices and each has merit for specific configurations.

Effort was also expended on the establishment of detail design data on geometric properties of bellows or corrugations and collapse pressures on spherical and longitudinal tanks with spherical heads.

Propellant Compatibility

In the design of propulsion systems, the propellants best suited for a specified mission are considered. However, the compatibility of the materials to these propellants must be carefully considered in the design of any expulsion device. A preliminary investigation of material and propellant compatibility is shown in Table I for several metals, elastomers and plastics.

Actually the material compatibility is also a function of the environment and propellant temperature and the results depicted in the above-mentioned figure are in the range of room temperature for the storable propellants.

Radiation

Space systems must also be capable of operating in a nuclear radiation environment. These systems will be subjected to either space radiation or that from nuclear reactors present in the vehicle. Associated systems will therefore be subjected to both of these radiations. This means that the components will receive gamma and neutron radiation in addition to the higher energy proton radiation (In the inner Van Allen belt)

TABLE I

MATERIAL-PROPELLANT COMPATIBILITY DATA

	PROPELLANTS							
	LIQ. HYDROGEN	LIQ. OXYGEN	LIQ. FLUORINE	N_2O_4	UDMH	N_2H_4	MON (Mixed Oxides of Nitrogen)	50% UDMH/50% N_2H_4
METALS								
1100-0 Aluminum	X	X	X	X	X	X	X	X
3003 Aluminum	X	X	X	X	X	X	X	X
6061 Aluminum	X	X	X	X	X	X	X	X
Nickel (Electro-deposited)	X	X		X	X		X	
ELASTOMERS								
Butyl Rubber					X+	X		X
Neoprene					X+	X+		
Genetron				X			X	
PLASTICS								
Teflon (TFE)	X	X	X*		X	X	X	X
Teflon (FEP)	X	X	X*		X	X	X	X
Kel-F (Unplasticized)				X+	X	X+	X+	X
Kel-F (Unplasticized) over Silicone Rubber				X+	X	X+	X+	X
Mylar	X	X						
Polyetylene				X+	X+	X	X+	X+
Nylon						X+		X+

*Static Seals only (no flow involved)

+Short term service only (less than 30 days)

and the Bremsstrahlung radiation (X-ray) due to the electron in either the inner or outer Van Allen zones.

Table II presents some data on the effect of nuclear radiation on the relative radiation stability of elastomeric and plastic materials. This information gives the effects of gamma radiation for tests conducted on relatively thin specimens in an environment of air. Metals do not show any appreciable change in properties for radiation dosages below 10^{11} and 10^{12} rads.

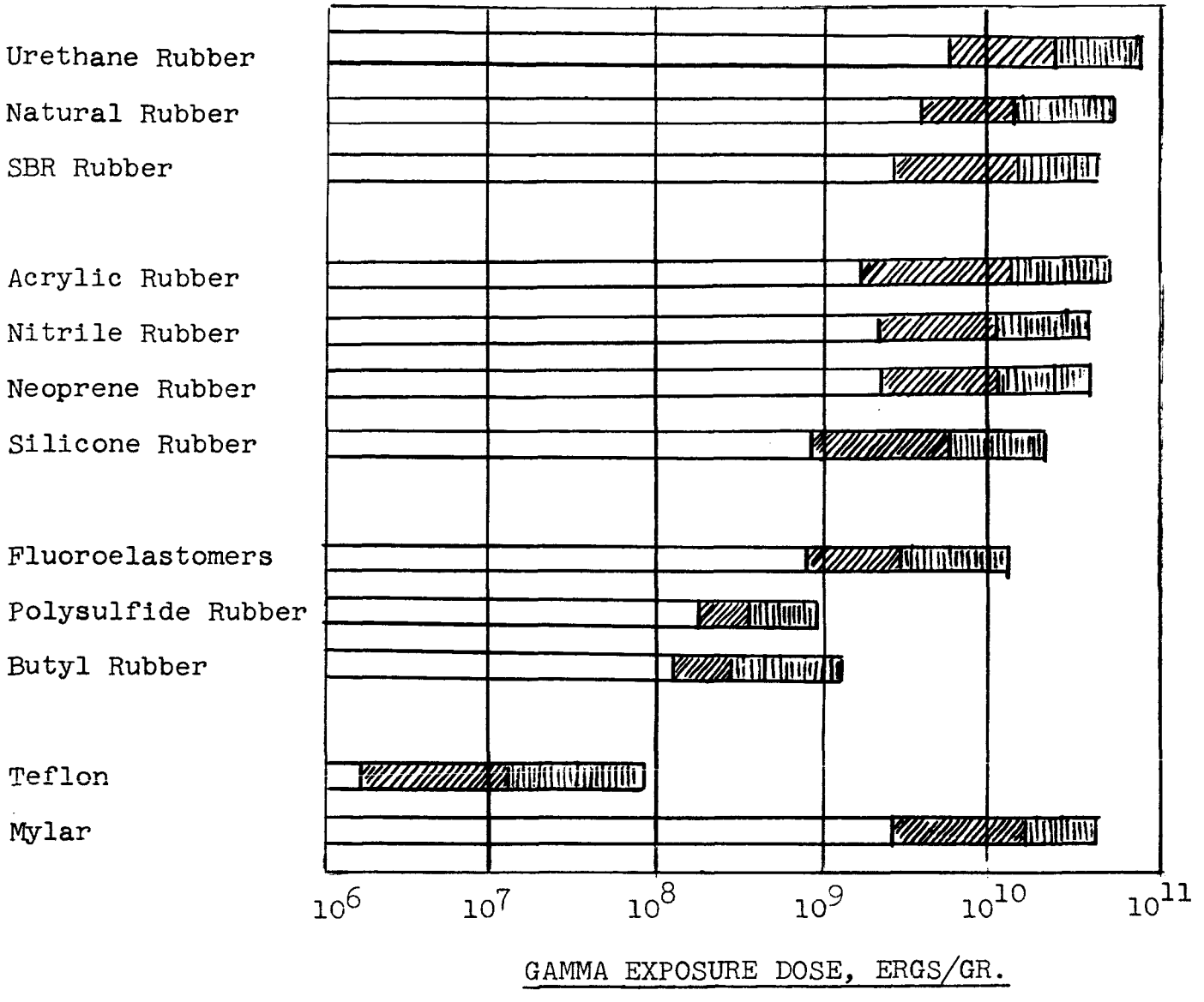
Bell Aerosystems Company has been conducting a radiation test program in connection with a USAF liquid rocket propulsion system contract. This system employs an actual positive expulsion bladder-tankage unit containing storable liquid propellants. The bladder was teflon and the tank system was loaded approximately 25% full of propellant. The outside of the partially filled bladder was pressurized using N_2 gas, thus simulating the actual configuration and condition.

All irradiations were performed at Argonne National Laboratory's High Level Gamma Facility using spent fuel rods as the source of gamma radiation. Each tank tested, oxidizer and fuel, received 1/2-million rads dosage at a dose rate of 100,000 rads per hour. It was concluded that this dosage did not cause a malfunction of either tank assembly.

Samples of propellants subjected to the various dosage levels received on this program were analyzed before and after radiation test. MON showed no change in composition up to an integrated dosage of 2.3×10^7 rads. UDMH did show some decomposition.

TABLE II

RELATIVE RADIATION STABILITY OF ELASTOMERS AND PLASTICS



Based on the radiation data gathered to date on the tank assembly, the following generalizations and conclusions can be drawn:

1. Teflon, a favored material of construction for positive expulsion system bladders, is not per se as radiation sensitive as originally thought. The ambient environment in which the teflon receives the radiation determines to a large extent the radiation dosage at which a given change in physical properties will occur.

2. For the conditions and dose rates employed during these tests, teflon does not exhibit any appreciable dose rate dependence. The integrated dose is the principal parameter determining the depreciation of physical properties.

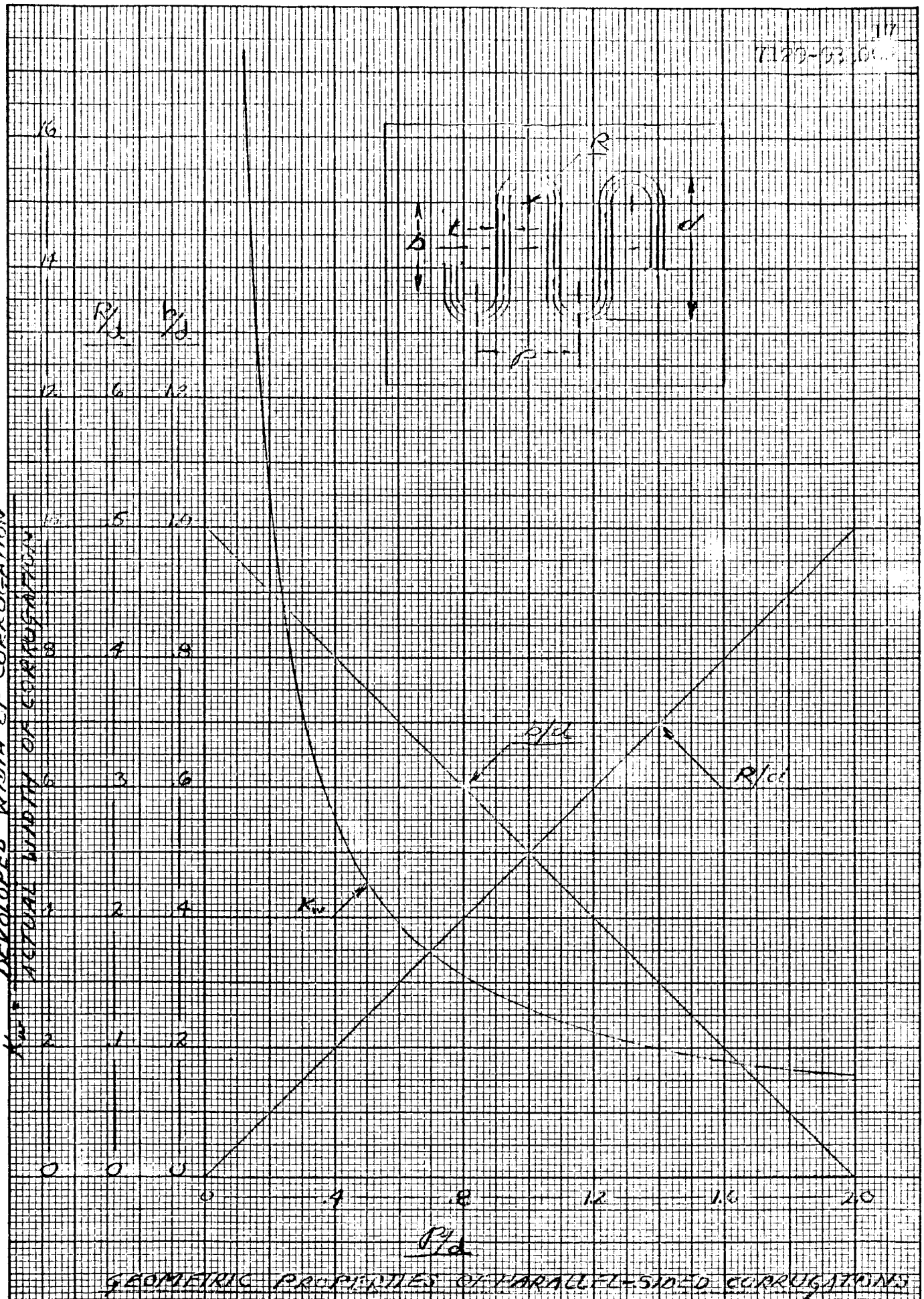
3. The upper level to which this type of bladder should still be operable is between 1 and 2 million rads. This is much higher than that which would have been predicted based upon presently published results.

Geometric Characteristics of Bellows

The graph on page 17 represents the geometric characteristics of parallel-sided corrugations that establish the size required for a given developed width of material. In addition this curve also provides the weight of material involved for a specific design configuration.

External Collapse Pressure on Tanks

In the application of an expanded bladder as a positive expulsion device, the buckling or collapse of the bladder under



GEOMETRIC PROPERTIES OF PARALLEL-SIDED CORRUGATIONS

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an external pressure initiates expulsion of the fluid within the bladder. The external collapsing pressure of a bladder represents the initial pressure differential between the pressurizing gas medium and the start of the fluid expulsion flow.

The external pressure required to collapse a thin walled circular cylinder with hemispherical heads is shown in the figure on the following page. This figure gives the buckling or collapse pressure as a function of diameter-to-thickness ratio, D/t, and length-to-radius ratio, ℓ/a, for any material. As ℓ/a approaches zero, a spherical container is approached which is the upper limit for the data presented. For ratios of $\ell/a > 1$, the critical pressure is governed by the cylinder behavior.

For values of $\ell/a > 1$ the curves presented in the figure on page 19 were obtained from relationships derived in References 1 and 2 for the buckling of circular cylinders with simply supported edge conditions. Since, for the configuration under consideration, the hoop stress in the cylinder is greater than the stress in the sphere by a factor of two for the same material thickness, it is reasonable to assume that the spherical shell ends will provide sufficient elastic support to the cylinder so that it can be considered as simply supported.

For very short cylinders, $\ell/a < 1$, it is substantiated in Reference 3 that the cylinder buckles essentially as a plate. A comparison of the results given for very short shells in Reference 3 and for spherical shells in Reference 4 reveals that there is a range of ℓ/a values for which very short cylinders

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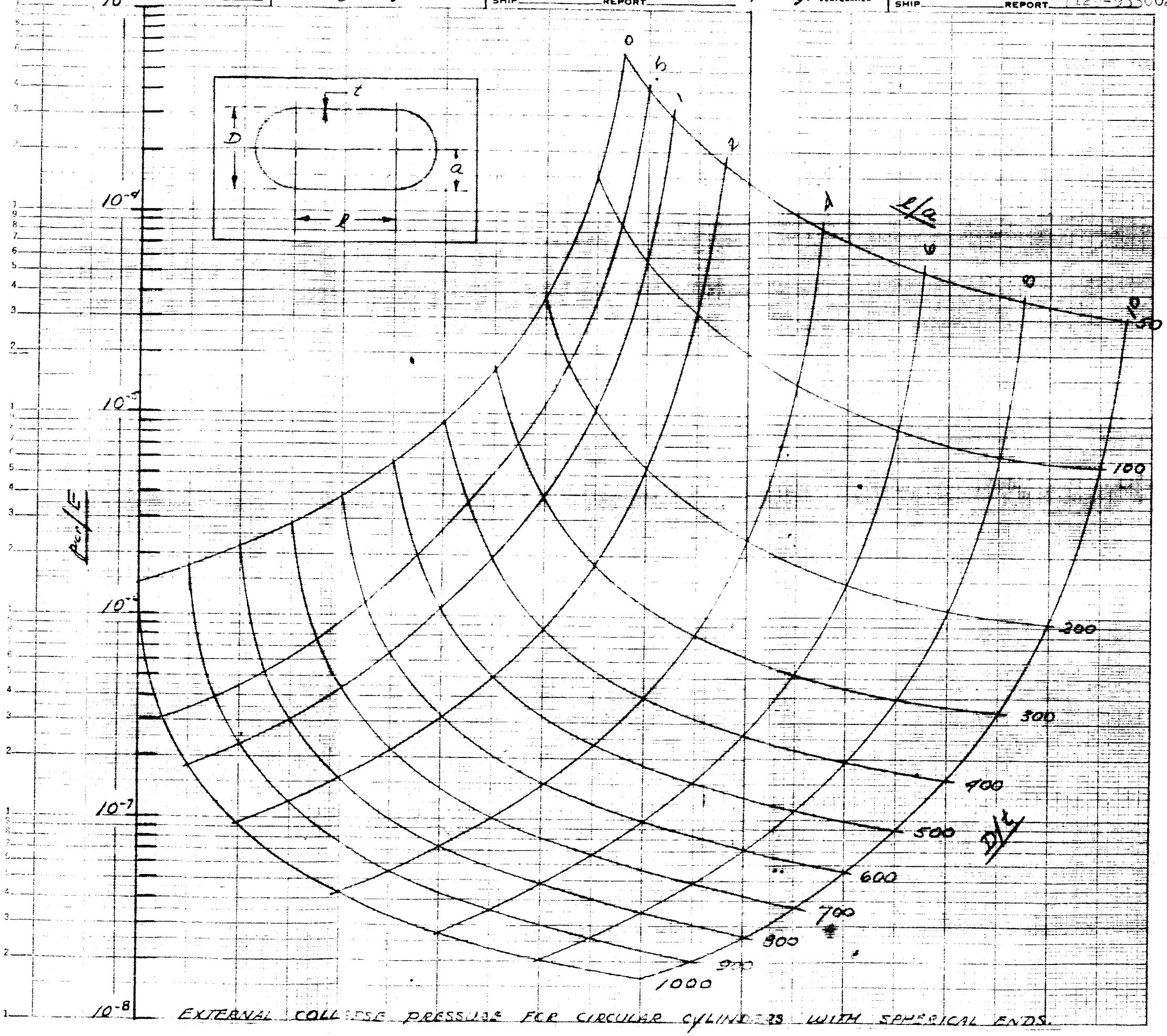

EXTERNAL COLLAPSE PRESSURES FOR CIRCULAR CYLINDERS WITH SPHERICAL ENDS.

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will buckle at an external pressure which is greater than that for the sphere. From these observations it can be concluded that in the range of $0 \leq \ell/a \leq 1$ there is a buckling interaction between the sphere and the cylinder. The external collapse pressure in this range of ℓ/a was approximated by interpolation between the collapse pressure derived for a spherical shell in Reference 4 and that for cylinders with $\ell/a \geq 1$. The results presented in Reference 3 for very short cylinders were employed as a guide in the interpolation process.

TECHNICAL REVIEW MEETING

On October 10, 1961, Mr. Henry Burlage, NASA Project Manager on the subject contract and Mr. Richard Porter, Technical Monitor on the program visited Bell Aerosystems Company to review the work performed.

During the discussions, the following items were mentioned:

1. The "distant-acting-force" field concept of expulsion should be expanded and a further study on such "exotic" and other devices should be made.

2. The preliminary evaluation scheme and characteristics of expulsion systems should be described and defined in depth. Definitions of the characteristics of the rating systems should be explained. In some instances, qualitative values only can be stated and in others it may be questionable to quote any value.

3. No hardware or fabrication and associated device testing is contemplated. Thus the test program for a selected device has been de-emphasized.

4. Exploratory laboratory tests can be performed to justify or evaluate critical characteristics and/or novel features of device components or materials.

5. Permeability test data that is available at Bell Aerosystems Company should include descriptions of the methods and analytical procedures employed when incorporated in the final report.

FUTURE WORK

As a result of the technical review meeting and discussions, work will be continued in the performing of the tasks indicated below. The main outcome of the work review is that the device test program is de-emphasized.

1. The "distant-acting-force-field" concept of expulsion devices will be expanded and studies will also be pursued for other expulsion device concepts.

2. The characteristics of the expulsion systems examined will be described and defined in depth and quantitative value will be applied to those characteristics already known.

3. An exploratory laboratory test program will be initiated to define, evaluate or justify the critical unknown characteristic that affects the selection of a specific expulsion device.

4. Permeability tests will be run to obtain a correlation between the effects of pressurizing with helium versus nitrogen gas on storable oxidizers, (nitrogen tetroxide and/or MON) when using plastic materials.

5. Compile additional data on expulsion device materials and investigate new candidate materials or material compounds. Perform small scale swatch tests of material specimens if necessary.

Both cylindrical and spherical plexiglass test tanks are available for use on this contract from existing test programs, and other off-the-shelf hardware and equipment will be employed wherever feasible if tests are found to be essential.

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